Wave Velocities below the Mohorovičić Discontinuity*

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Summary

The velocities of longitudinal waves immediately below the Mohorovičić discontinuity which have been found by various authors for continental regions decrease on the average from about 8·2 km/s, if the Mohorovičić discontinuity is at a depth of 30 km, to about 8·0 km/s, if it is at a depth of 50 km. The rate of this decrease in velocity of $0·011 \pm 0·0016$ km/s per km is statistically significant and exceeds appreciably the critical rate of about 0·0013 km/s per km, required for a low-velocity channel. The corresponding calculated average decrease in the velocity of transverse waves from about 4·64 km/s, if the Mohorovičić discontinuity is at a depth of 30 km, to about 4·56 km/s, if it is at 50 km (at a rate of $0·004 \pm 0·0056$ km/s per km) can be expected to represent average conditions under continents only if this decrease in velocity is considered in connection with that for longitudinal waves. For a depth of about 60 km, both calculated velocity-depth curves connect smoothly with those found by the author from the apparent velocities at the points of inflection of travel-time curves for earthquakes originating at various depths. The new results confirm the hypothesis that under continents the asthenosphere low-velocity channel starts at the Mohorovičić discontinuity.

Various seismologists have calculated the depth of the Mohorovičić discontinuity and the wave velocities immediately below it on the basis of travel-time curves found from supposedly refracted waves recorded after nearby earthquakes or artificial explosions. A number of such data reported during the past ten years for continental areas are given in Table 1. A plot of these velocities in Figure 1 shows that the resulting velocities V for longitudinal waves decrease definitely with increasing depth h of the Mohorovičić discontinuity, while the corresponding velocities v of the transverse waves show a less definite decrease with increasing h.

If we assume that the velocities for both wave types change linearly with the depth h in the range between $h = 26$ km and $h = 50$ km, for which data are available, the method of least squares gives the following relationships:

$$V = (8·08 \pm 0·013) - (0·011 \pm 0·0016)(h - 40) \text{ km/s}, \quad (1)$$

$$v = (4·60 \pm 0·044) - (0·004 \pm 0·0056)(h - 40) \text{ km/s}. \quad (2)$$

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Table 1

Velocities V of longitudinal and v of transverse waves and depth h of the Mohorovičić discontinuity reported for various continental regions. A *and* E *in the last column indicate whether the results are based on artificial explosions or on earthquakes respectively.*

Region	Author	h km	V km/s	v km/s	A,E
NW Germany	Reich, Förtsch, Schulze (1951)	26	8·32	4·58	A
NW Germany	Reinhardt (1954)	27	8·19	—	A
NW Germany	Willmore (1949)	28	8·18	—	A
Bavarian Alps	Reich (1958)	28	8·2	—	A
Black Forest	Rothé (1958)	30	8·2	4·4	A
SW Germany	Hiller (1953)	30	8·1	4·7	E
Bohemia	Kárník (1956)	31	8·15	—	A
Alaska	Aldrich & others (1957)	31	8·1	—	A
Po Valley	Caloi (1958)	32	8·16	4·52	E
Kyoto	Kishimoto (1955)	32	8·1	4·7	E
U.S.A., Atlantic coast	Adams & others (1952)	33	8·1	—	A
S. Africa	Gane & others (1956)	34	8·22	4·70	A
Pennsylvania, New York	Katz (1953)	34	8·14	4·69	A
Hungary	Vanek (1955)	35	8·14	4·53	E
SE of Lake Balkash	Gamburtsev, Veytsman (1956)	35	8·1	—	A
S. California	Gutenberg (1952)	35	8·15	4·5	A
West Australia	Bolt & others (1958)	35	8·21	4·75	A
Canadian Shield	Hodgson (1953)	36	8·18	4·85	A
East Transvaal	Hales, Sacks (1959)	37	7·96	—	E
West Australia	Doyle (1957)	37	8·18	4·72	A
NW of Lake Issik Kul	Gamburtsev, Veytsman (1956)	38	8·1	—	A
NE of Lake Balkash	Gamburtsev, Veytsman (1956)	40	8·1	—	A
Wisconsin	Slichter (1951)	42	8·17	—	A
Central Appalachians	Adams & others (1952)	45	8·06	—	A
N. of Lake Issik Kul	Gamburtsev, Veytsman (1956)	45	8·1	—	A
S. Alps	Caloi (1958)	45	8·0	4·41	E
NE India	Anonymous (1955)	46	7·91	4·46	E
Caucasus depression	Balavadze, Tvaldvadze (1957)	49	8·0	4·65	A
Central Asia	Bune, Butovskaya (1955)	50	8·0	—	A
Chilean Andes	Aldrich & others (1958)	50±	8·0±	—	A

Both lines are shown in the respective portions of Figure 1. While the rate of velocity decrease with h for longitudinal waves is statistically significant, the numerical result for the corresponding rate for transverse waves is not. However, the fact that its trend is similar to that for longitudinal waves makes it very probable that the rate of decrease in the transverse velocity given by equation (2) is not far from correct.

The deviations of the observed values from the calculated straight lines have various causes. First, the basic data of Table 1 are affected by errors. The waves on which the calculated velocities are based are rather small; as a consequence of the low-velocity channel below the discontinuity, they are diffracted. In several instances, different authors have arrived at somewhat different velocities on the basis of the same records (for example, for the Heligoland explosion, first three lines of Table 1). Frequently, this is a consequence of different interpretation of the recorded phases. Tilt of the Mohorovičić discontinuity, effects of variable structure of the Earth's crust, and differences in the material below the discontinuity may produce additional errors. Moreover, the assumption of linear equations connecting the velocities and the depth h is only an approximation.

The greater scattering for v than for V results partly from the fact that longitudinal waves refracted below the Mohorovičić discontinuity are the first waves in seismograms recorded beyond a certain distance from the source, while transverse waves always arrive at times when the motion from earlier waves has not completely subsided. Moreover, frequently no clear transverse waves are recorded from artificial explosions.

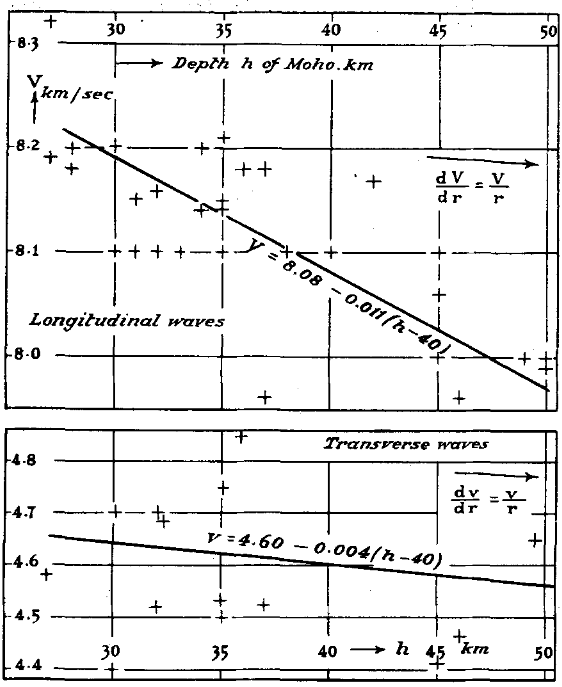

FIG. 1.—Velocities V of longitudinal waves and v of transverse waves observed in continental areas below the Mohorovičić discontinuity as function of its depth h in km.

Results from explosions in oceanic regions cannot be combined with results obtained in continental areas. First, there is a greater probability of differences in material below the Mohorovičić discontinuity. However, even if the material is the same, the differences in temperatures at a given depth under oceans and under continents may produce noticeable differences in wave velocities; the effect of differences in pressure is probably smaller. Data from ten different localities in the Pacific Ocean with depths h of the discontinuity between 9 and 20 km (average 12·7) indicate velocities V of between 7·9 and 8·4 km/s (average 8·16) while similar data from the Atlantic Ocean with h between 10 and 14 km (average 12 km) give values for V between 7·9 and 8·1 km/s (average 7·98 km/s). Similarly, in New Zealand values of 7·9 to 8·1 km/s have been found for V and about 4·5 km/s for v corresponding to h = 20 km (Eiby 1958).

Extrapolations of the equations (1) and (2) indicate that V and v decrease to about 7·75 and 4·48 km/s respectively at a depth of 70 km. Unpublished values found by the author by use of the apparent velocity at the point of inflection of travel-time curves for earthquakes at intermediate depth (compare Gutenberg

1953) give about 7·8 and 4·44 km/s respectively for depths of about 80 km. These new velocity–depth curves for depths greater than 60 km merge into the lines given by Equations (1) and (2) without marked discontinuity. Representative values for V and v as a function of depth down to 400 km are listed in Table 2. It does not seem likely that the final values resulting from a revision for depths greater than 60 km, now under way, will result at any depth in changes in excess of 0·1 km/s for longitudinal waves and of 0·05 km/s for S.

Table 2

Representative values of the velocity V of longitudinal waves and v of transverse waves in km/s and of Poisson's constant σ in the upper portion of the Earth's mantle under continents as a function of the depth d in km

(*July* 1959)

d	40	50	60	70	80	100	150	200	250	300	350	400
V	8·08	7·97	7·87	7·82	7·80	7·82	7·95	8·1	8·3	8·55	8·75	9·0
v	4·60	4·55	4·51	4·47	4·44	4·42	4·40	4·43	4·53	4·65	4·78	4·93
σ	0·26	0·26	0·26	0·26	0·26	0·265	0·28	0·29	0·29	0·29	0·29	0·29

On the basis of the new results there can be little doubt that the asthenosphere low-velocity channel starts for both wave types immediately at the Mohorovičić discontinuity. It also appears that the differences in velocities found in various continental regions immediately below the Mohorovičić discontinuity depend mainly on the depth of the discontinuity and, except perhaps for areas near the oceans, not so much on local conditions below the crust. A detailed description of the increasing number of other methods and phenomena which support the hypothesis of the asthenosphere low-velocity channel has been given by Gutenberg (1959, pp. 75–89).

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